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SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

[redacted]

UNPUBLIS

OPTICAL SATELLITE TRACKING PROGRAM

Carried out under a grant

from the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semiannual Progress Report No. 8

[redacted]

CAMBRIDGE, MASSACHUSETTS 02138

8104903 SMITHSONIAN ~~INSTITUTION~~
ASTROPHYSICAL OBSERVATORY, CAMBRIDGE, MASS.

OPTICAL SATELLITE TRACKING PROGRAM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semiannual Progress Report No. 8,

(January 1 through June 30) 1963

Supp. $\boxed{2}$

Project Director: Fred L. Whipple 30 JUN. 1963 34P REFS

(NASA GRANT NSG-87)

(NASA CR-55652)

Cambridge, Massachusetts 02138

[redacted]

TABLE OF CONTENTS

DATA ACQUISITION

STATION OPERATIONS

(Baker-Nunn camera stations)

During the period of this report, Station Operations continued to track satellites both on assignment from the National Aeronautics and Space Administration, and for special needs of Observatory scientists (see tables 1 and 2); photographed comets Humason, Ikeya and Alcock; further developed the new EECo timing system; modified the observer training program; and maintained the twelve Baker-Nunn camera stations.

Precision timing system

The prototype of the EECo precision timing system was successfully field tested at the South African tracking station. From 19 January to 25 March 1963 the clock received signals from all of the major VLF stations, including Hawaii. Thus we established the feasibility of operating the system indefinitely in synchronism with a VLF standard-frequency transmission.

An important part of the testing program was the comparison of the performance of three commercially available VLF receivers. Our experience with the prototype system has permitted us to improve the specifications for production units.

The prototype is now installed at the Florida station.

Observer training program

We have established a six-week program to train prospective observers for their duties at the Smithsonian optical tracking stations. Trainees spend three weeks in Cambridge and three at the Florida tracking station. To date, 13 men have been trained and placed at eight of the field stations.

Table 1

COMPARISON OF OPERATIONAL RESULTS

January-June 1962-1963

Number of Predictions

Month		1962	1963
January		5813	5215
February		5407	5771
March		7202	6160
April		7806	6074
May		5808	7069
June		5684	6996
	Total . . .	37720	37285

Number of Successful Observations

Month		1962	1963
January		2024	2005
February		1889	2424
March		2271	2486
April		2407	2348
May		2249	2675
June		2548	3080
	Total . . .	13388	15018

Increase in number of successful observations - 12%

Monthly Station Average

Average/month/station	1962	1963
Predictions	524	518
Observations	186	209

Table 2

SUCCESSFUL OBSERVATIONS BY INDIVIDUAL TRACKING STATION

January 1 through June 30, 1962 and 1963

Station	Number of Successful Observations 1962	1963
New Mexico (SC-1)	1798	1594
South Africa (SC-2)	1870	1919
Australia (SC-3)*	1811	1823
Spain (SC-4)	747	1076
Japan (SC-5)	965	905
India (SC-6)	356	1708
Peru (SC-7)	822	593
Iran (SC-8)	1134	1272
Curaçao (SC-9)	786	883
Florida (SC-10)	871	966
Argentina (SC-11)	875	1337
Hawaii (SC-12)	1353	1052
Totals . . .	13388	15018

*The statement on p. 1-6 of Report Number 7 that the annual efficiency of SC-3 is 62 percent should be amended to read 59 percent.

Each trainee participates in the work of the various departments directly associated with the processing of Baker-Nunn films and records. By actually exposing, evaluating and measuring films, and reducing the associated time records, he gains an over-all appreciation of the various problems and rigorous procedures associated with the acquisition and subsequent reduction of observational data. The trainee attends descriptive lectures on equipment usage, with emphasis on electronic and mechanical repair and maintenance. The very latest improvements and procedures are explained directly to him by the engineering staff, working supervisors and department heads.

Each candidate is evaluated by the experienced personnel of the various departments, which procedure helps us to recognize individual talents and interests, as well as to detect unsuitable candidates. Each trainee is also encouraged to make the evaluation mutual.

Recently, in cooperation with the Personnel Division, we have expanded the training course in Cambridge to include professional language instruction. The first two men to participate in this program are now in training in Cambridge.

Already we are noticing certain beneficial results from the formal training program, among them increased uniformity of operating procedures and a consequent increase in system efficiency.

Equipment and instrumentation

Basic equipment at the stations operated satisfactorily with routine mechanical and electrical maintenance.

Station vehicles.--A new Ambruster crew-cab conversion and a Chevrolet pickup truck at Peru replace the 1959 Ford pickup truck, which we donated to the University of San Agustin in lieu of our paying the annual $500 fee. We also received a Chevrolet sedan to replace the Willys jeep at Peru. A Ford pickup truck was shipped to the Argentina station.

Mechanics and optics of Baker-Nunn cameras.--We re-aluminized the Argentine primary mirror in January. Bids are in for the Florida mirror re-aluminizing; the work will be done later this summer. We hope to have a thirteenth mirror in circulation late in the summer, which will allow us to re-aluminize all other mirrors over a 12- to 18-month period. At the same time we will rework the corrector cells and install corrector-cell windows.

We have requested bids for repolishing and reworking one corrector cell, and have obtained bids for refurbishing the corrector cell removed from the Curaçao tracking station.

We have also obtained bids for grinding and polishing the flat optical "window" of BK-7 glass to be installed on every reworked corrector cell to protect it from dust, stains, and water.

A new mechanical slave clock has been developed as a substitute for the Boller and Chivens unit now used in conjunction with the Norrman Time Standard. The new unit is also suitable for use with the geodetic camera. A smaller model is being machined.

Norrman timing system.--We are continuing the program to improve the operation of the Norrman Time Standard through better training and better maintenance.

Voltage regulators have been installed in all stations except Japan, where none is required. We have initiated the use of triggered-sweep oscilloscopes for improved time-signal interpretation in Argentina and Peru. An improved WWV receiver has been supplied to the Peru station. A Sulzer oscillator has been installed in Iran. The operation of this oscillator and those previously installed in Japan and India has proved quite successful. Similar oscillators have been ordered for the remaining stations. These oscillators will later be incorporated into EECo precision timing systems.

We are continuing the study of timing inaccuracies as part of a program to detect and correct sources of major difficulty in the existing equipment, with particular attention to incoming timing data.

Instrumentation studies

Vibration signatures are still being collected and analyzed.

The darkroom installation in Cambridge has been completed. The test of a general sensitometric quality-control procedure is now being set up.

A drafting pool and a mechanical shop have been established at 185 Alewife Brook Parkway.

Continuous graphs are being maintained on weekly focus-plate tests.

Plans

We plan to get six production units of the model precision timing system, and to install Sulzer oscillators at all stations.

MOONWATCH

The Moonwatch Program now consists of 12 "precision," 22 "standard," and 121 "limited" teams and independent affiliates. The teams produced 3230 visual observations of approximately 100 satellites and components. Moonwatch observations since October of 1957 total more than 52,000.

Operations included attempts to observe selected re-entering satellites; training and proficiency observing; and pre-entry observing. Special bulletins provided technical advice and instruction to visual observers. Thus new affiliates learn the basic requirements for effective observing, and experienced observers learn prediction shortcuts and special techniques for pre-entry observing.

Seventy-three pre-entry observations were made on Cosmos V. These and other intensive and successful pre-entry efforts yielded no successful re-entry observations, since final revolution forecasts were inaccurate, and trajectories apparently occurred over areas not covered by Moonwatch or other ground-based sensors. Since accurate forecasts depend on reliable late pre-entry observations, we are trying to increase sensor data during critical periods.

Moonwatch made one daylight observation of Faith VII during its third revolution.

Table 3

MOONWATCH OBSERVATIONS

January through June 1963

Year	Satellite	Observations Received
1958	Alpha	131
	Beta 1	54
	2	1
1959	Alpha 1	44
	2	57
	Eta	70
	Iota 1	121
1960	Beta 1	3
	Gamma 2	2
	Epsilon 3	13
	Zeta 1	16
	Eta 1	15
	2	5
	3	3
	Iota 1	447
	2	142
	3	27
	4	2
	5	27
	Nu 1	15
	2	31
	Xi 1	59
	Pi 1	1
1961	Alpha 1	13
	2	2
	Delta 1	287
	Nu	27
	Omicron 1	127
	2	76
	3	1
	(Rest)	4
	Rho 1	1
	2	1
	Sigma 1	78
	A-Delta 1	21
	A-Eta 1	4
	2	2
1962	Beta 1	5
	4	5
	Zeta 1	1
	2	7
	Eta 1	2
	Iota 1	11
	Kappa 1	30
	3	3
	4	1
	Omicron 1	5
	2	1

Year	Satellite	Observations Received
1962	Sigma 1	3
	Upsilon 1	68
	Omega 1	50
	A-Alpha 1	7
	A-Epsilon 1	96
	2	38
	A-Xi 1	13
	A-Upsilon 1	77
	A-Psi 1	9
	B-Alpha 1	14
	2	51
	B-Theta 1	49
	2	82
	B-Kappa	99
	B-Mu 1	103
	2	10
	B-Tau 1	2
	2	4
	6	8
	B-Upsilon 1	2
	2	21
	B-Chi	24
	B-Psi 1	8
1963	3-A	17
	5-A	12
	9-A	7
	B	9
	10-A	19
	B	27
	11-A	1
	B	4
	12-A	9
	B	9
	13-A	22
	B	39
	14-A	33
	C	8
	D	1
	17-A	54
	B	9
	C	2
	D	1
	E	3
	G	78
	18-A	4
	B	7
	19-A	1
	21-A	1
	23-A	1
	Total	3230

COMMUNICATIONS

During the period of this report, the Division continued to provide communication service for the satellite-tracking system and for other space agencies. The communications center handled an average of 1.9 million words per month.

New services, circuits, and equipment

We completed arrangements for unlimited use of the General Services Administration telecommunication facilities, which allow us telegraphic communication to all major cities in the United States at a cost saving of some 70 percent over commercial systems. This system is now the primary route to the Baker-Nunn stations in Florida and New Mexico.

The Federal Agencies Consolidated Telephone System became operational in February with leased telephone service to 42 major cities. SAO was granted full membership in this system and now uses its facilities at substantial cost savings.

In March we increased attended switchboard service to include Saturdays from 9:00 a.m. to 5:00 p.m.

Our military telegraphic outlet, the U. S. Navy 82B1 Teletypewriter Switching System, was converted from 75 to 100 words per minute.

In April the configuration of our direct line to the Goddard Space Flight Center was altered to allow the NASA Marshall Space Flight Center at Huntsville, Alabama, to share the circuit. This change expedites message traffic between Goddard and Huntsville and provides an alternate route between the NASA Scientific Satellite Communication Network and the NASA Administrative Network. Now sharing the circuit are SAO, Marshall Space Flight Center, and the U. S. Government Graphic Arts Office, Washington, D. C.

A Western Union TELEX unit was installed in the SAO Communication Center in May. Its primary purpose is to provide an alternate route to the Goddard Space Flight Center, and, through Goddard's relay facilities, to the Baker-Nunn stations in Australia, South Africa, Argentina, and Peru. Its secondary purpose is to provide direct and indirect transmission to all agencies throughout the world that subscribe to this system.

In June the Communications Division moved from 60 Garden Street to 185 Alewife Brook Parkway. Circuits were out of service for only four hours. This move into more spacious quarters has allowed us to reorganize certain operating techniques and to change some of our procedures. We now have separate facilities for incoming and outgoing messages; we have refined our record-keeping, have improved our tape storage, and have provided a working area for Moonwatch and Station Operations personnel to use during launch and special search periods.

With the concurrence of the Communications Officer of the First Naval District we accepted an alternate-route responsibility for urgent satellite messages originating at the Spacetrack R and D Facility at L. G. Hanscom Field, Bedford, Massachusetts.

In June, the Lincoln Laboratory circuit was discontinued, and the equipment was removed.

Soon after our move to Alewife Brook Parkway we installed an IBM-47 tape-to-card machine in the Communications Center.

Publications

The monthly Satellite Situation Report issued by this division has been expanded to show the status of all objects launched and to summarize recent activity.

Plans

The IBM-47 tape-to-card equipment will be incorporated into the Communications Center's operating system. When operational, this promises substantially to reduce the time between received observations and computer input.

Auxiliary power like that provided at 60 Garden Street is not available at our new quarters at 185 Alewife Brook Parkway. We will determine the feasibility of providing the Communications Center with an alternate power supply during city power failure.

DATA PROCESSING

DATA DIVISION

The Data Division computes predictions of satellite positions for the various satellite-tracking stations; derives orbits from observations made by Baker-Nunn, Moonwatch, or other tracking stations; prepares smoothed and mean orbits (from both field-reduced and photoreduced data) for publication in SAO Special Reports; records information that may affect research on satellite orbital data; publishes predictions, orbital elements and equator crossings; and handles the routine technial correspondence of the satellite-tracking program. The division is also responsible for preparing and publishing the SAO Star Catalog.

Nominal and revised early-tracking predictions were derived for all NASA launches for the Baker-Nunn cameras and some Moonwatch stations. These totaled 1479 predictions for six objects.

We processed the normal Baker-Nunn, Moonwatch and miscellaneous observations and derived orbits each week, using the Differential Orbit Improvement program. These orbits were used to produce predictions, by means of the Scroge and Ephemeris II programs, for the Baker-Nunn and selected Moonwatch sites. Breakdowns of predictions and observations are included in the sections on Baker-Nunn and Moonwatch system operation. The network regularly tracked 17 satellites.

Following is a list of satellites that SAO was responsible for tracking during this period: 1958 Alpha 1, 1959 Alpha 1, 1959 Eta 1, 1959 Iota 1, 1960 Iota 1, 1960 Iota 2, 1960 Xi 1, 1961 Delta 1. SAO distributes orbital data on these objects for prediction.

Mean and smoothed orbital elements were derived and published for the satellites listed in table 4.

Table 4

Satellite	Special Report Number
1958 Alpha (Explorer I)	113, 117, 120, 126
1959 Alpha 1 (Vanguard II)	113, 117, 119, 120, 126
1959 Alpha 2 (Vanguard II Rocket)	119
1959 Eta (Vanguard III)	113, 117, 119, 120, 126
1959 Iota 1 (Explorer VII)	113, 117, 120, 126
1960 Xi 1 (Explorer VIII)	113, 117, 120, 126
1960 Iota 2 (Echo I Rocket)	119
1961 Delta 1 (Explorer IX)	113, 117, 119, 120, 126
1960 Iota 1 (Echo I)	117, 120, 126
1960 Gamma 2 (Transit 1B)	126

Observations of the satellites listed in table 5 were also published for this period.

Table 5

Satellites	Special Report Number
1958 Alpha (Explorer I)	114
1959 Alpha 1 (Vanguard II)	114
1959 Eta (Vanguard III)	114
1959 Iota 1 (Explorer VII)	114
1960 Iota 1 (Echo I)	115
1960 Iota 2 (Echo I Rocket)	115
1960 Xi 1 (Explorer VIII)	115
1961 Delta 1 (Explorer V)	116
1961 Omicron 1 (Transit 4A)	116
1961 Omicron 2 (Injun Solar Radiation 3)	116
1961 Upsilon 1 (Explorer XII)	116
1962 Zeta 1 (Orbiting Solar Observatory)	116
1962 Iota 1 (Cosmos 2)	116
1962 Iota 2 (Cosmos 2 Rocket)	116
1962 Nu 2 (Cosmos 3 Rocket)	116
1962 Omicron 1 (S51/UK1)	116
1962 Omicron 2 (S51/UK1 Rocket)	116
1962 Alpha 1 (Tiros I)	116

We prepared special predictions for tracking objects of particular interest to SAO. These included the MA-9 rocket body (Faith VII), Syncom, and various objects due to re-enter the earth's atmosphere. Predictions of such objects as ANNA and Echo were prepared for other tracking agencies that requested them. These predictions usually took the form of look-angles. Among the recipients were Mitre Corporation, Lincoln Laboratories, Air Force Cambridge Research Laboratories, Naval Research Laboratory, Raytheon Corporation, and Goddard Space Flight Center.

We are studying the feasibility of replacing the decoding, filing and handpunching of observations with a computer program. If adopted, this program is expected to eliminate up to 75 percent of the routine handwork of the Records and Distribution Section.

The Star Catalog introduction and description are being prepared for publication. Eleven-word format and BCD binary tapes are now ready for publication. All duplicate stars have been removed. We have added 36,000 spectral types to zones derived from the AGK2 catalogue. The first updated version of the ARP tape for photoreduction is in use. The nine-word format tape is to be finished soon. We are awaiting a purchase order for the plotter modification. This is necessary for the charts to be plotted and produced.

PHOTOREDUCTION DIVISION

From January through June of 1963, the Division increased reductions of observations to 11,898; received and cataloged 15,567 Baker-Nunn films; improved its instrumentation, techniques, and output; and carried on various special projects.

The SI-ARP preparation program

In February the division operation was converted to the long-awaited SI-ARP preparation program. This program, described in the section on the Computations Division, is designed to eliminate much of the tedious routine necessary to prepare a film for precise measurement and reduction. Briefly, the program performs the following:

Time Reduction.--A "time history" is now maintained on magnetic tape for each of the independent station timing systems. This tape gives the corrections that must be applied to a particular independent film time to convert it to the uniform system, A_1 (atomic time). Formerly, the time of each observation was manually reduced in the Time Reduction Section. Although the correction information for the time history tape must be hand computed, the over-all work load in the Time Reduction Section has been reduced to a point where a decrease in the section staff is being seriously considered.

Star Catalog.--Given the reduced time of a satellite photograph from a particular station, the preparation program uses a mathematical model of the orbit to determine its apparent position (as seen from the station in question) at the time of observation. Next, the program enters the SAO Star Catalog (described elsewhere in this report) and selects a configuration of reference stars in the vicinity of this position and records their coordinates (α, δ). It next computes the approximate Cartesian (x,y) coordinates of these stars (in microns) relative to the satellite on the film; i.e., the program "predicts" roughly where the reference stars will be found, relative to the satellite image on the film.

Using these rough predicted coordinates, a measurer then determines the precise coordinates of satellite image and reference stars, using a Mann two-screw comparator.

These precise measurement data are used along with catalog positions of the stars in a second computer program (automatic reduction), which produces the position of the satellite in right ascension and declination.

Under the old system a measurer selected the reference star configuration to be used. He then looked up in a star catalog the celestial coordinates of each star selected. Often several catalog volumes were needed for a single configuration, and the process was extremely laborious. The automation of catalog work has resulted in a 60 percent decrease in the time required to prepare a film for measurement and reduction.

Overhaul and modification of the Mann comparator

The badly needed overhaul and modification of our model 422D Mann comparator was completed in March. Unlike our four smaller model 829A Mann comparators, which were specially adapted for work over relatively small areas of Baker-Nunn films, the 422D was designed for work on larger astrographic plates. This engine is especially useful for projects that require measurement over extended areas (up to 9" x 9"), e.g., Baker-Nunn distortion studies, which use entire frames, meteor plates, geodetic camera plates, etc.

While the above work was being done at the Mann Company plant in Lincoln, Massachusetts, we took the opportunity to modify the engine's associated digitizing system. The fixed program board controlling read-out format was replaced with a plug-board system. Formerly, the program board had to be manually rewired each time a format change was required. Now we can accomplish a change in format by swapping prewired plug-boards. This feature has proven very useful, as the 422D system is often used for a variety of concurrent projects, each requiring different output formats.

Special projects

1. A major project--carried out in conjunction with our routine reduction effort--was the Division's participation in the ANNA 1B Geodetic Satellite Project. The unorthodox camera operation required (photographing a sequence of flashes separated by 5.6-second intervals) markedly increased the complexity of the reduction process. The Division technical staff, headed by I. G. Campbell, carried out the necessary programming and operation changes for the reduction of the flash photographs. Late in June the Division began producing ANNA reductions on a regular basis.

2. During March we completed measurements of a series of time exposures of Satellite 1960 Iota 2. This work was part of a satellite "tumble" study being done by Dr. Richard Giese.

3. In February we undertook, on a low-priority basis (not to interfere with routine production) to measure a series of films, exposed at the Maui Baker-Nunn station, to be used in a study of atmospheric refraction by Fred Fischback of the High Altitude Engineering Laboratory of the University of Michigan.

4. We assisted Project Celescope in testing ground-based data-handling equipment by measuring roughly 300 photographs of multiple A-scope and digital monitor presentations.

Routine reduction

Production of precisely reduced observations for use by the SAO scientific staff and others once again increased over the previous period. We completed a total of 11,898 reductions, despite various disruptions. We should note here that the new facilities, which were designed according to our own specifications, are more conducive to efficient operation.

The Film Control Section received and cataloged a total of 15,567 films from the Baker-Nunn stations. Of these 8,761 were evaluated for precise reduction. Our Cambridge storage facility now contains over 90,000 films.

The Film Exchange Program, which Mr. Kokaras initiated last October, has resulted in an increased interest in film quality on the part of the camera stations. Under this program each station each month submits film samples to the Film Control Section for critical evaluation. All films are graded according to over-all quality, and a sample of the "winning" film is distributed to all stations for comparison.

Equipment and instrumentation

We have acquired an IBM-026 printing card punch, which the Data Section uses to handle an increase in miscellaneous keypunching inherent to the new Preparation Program.

"Auxiliary Duplicate" and "Alternate Program" functions were installed on the keypunch machines associated with the five measuring systems. The purpose of this installation is to increase system flexibility and to reduce the time required to record the "bookkeeping" information that accompanies each measurement.

Plans

We will, with the cooperation of the Personnel Division, carry out a program of supervisory training for the benefit of section heads and the supervisors of the astrometric group.

We will continue our long-range program of equipment improvement.

COMPUTATIONS DIVISION

This Division provides programming and computing facilities, using IBM-7090 time purchased through Harvard University.

Projects completed

Combination of Least Squares.--The theory and implementation of this program were described in Semiannual Progress Report No. 7 and in SAO Special Report 122. We have brought the project to a satisfactory conclusion.

Laplace Coefficients Program.--The purpose and design of this program were described in Semiannual Progress Report No. 7. Although this program is part of a larger project, described in the Research and Analysis section of this report, it can be used as a subroutine to generate tables of the Laplace coefficients and their derivatives to the twelfth order, and to plot these functions on the EAI data plotter. Though this program is only part of a long-range project, we consider this phase complete. We are now awaiting results from the M.I.T. Cooperative Computer Center.

Projects continued

Differential Orbit Improvement Program (DOI).--We have successfully completed the optional inclusion of Lunar perturbations in the DOI and have incorporated into the program the revision of the input-output routines, which led to a general input-output routine package (GIO). Utilizing the latest input-output techniques, GIO reduces running time 10-20 percent. This new program, known as the DOI-3, has computed 14 consecutive orbits in 3.5 minutes on the 7090.

Automatic Reduction Program (ARP).--Changes in the input data resulting from new measuring techniques have necessitated changing the reduction process. This optional program is used primarily with measurements resulting from the preparation program described below. Improvements in the least-squares solution have also been included. We have tried to generalize the input in order to make the deck preparation easier and to reduce the likelihood of error.

Preparation Program.--This program, which is now completely operational, is used exclusively by the Photoreduction Division. We are still adding to the program such minor modifications and extensions as increasing the number of stars requested for a reduction.

Star Catalog.--The programming for compiling the final catalog and for producing the printed version is, for all intents and purposes, completed.

Tesseral Harmonics.--We are still working on this program, although we have had certain versions of it in production for some time. The major advance has been the incorporation of a more accurate matrix-inversion program and the extension of the program to compute higher harmonics.

Automatic processing of observations.--We are writing a program to process automatically the observations received at SAO through the teletype network. The intent of this project is to speed the processing of observations by

a) eliminating bad observations by comparing these observations with the predictions and performing simple consistency checks;

b) reducing the paperwork required to process the observations;

c) hopefully, reducing the need to decode by hand the majority of the observations; and

d) producing, directly from the teletype message, observation cards acceptable to the DOI program, thus eliminating keypunching. This is being programmed for the 1401 computer. Preliminary estimates are that 600 observations can be processed in 20 minutes in this fashion; it would take two people five days to do the same task by the method formerly used. This project was made possible by new punch-paper-tape-to-punchcard equipment installed on 26 June.

Long-period integration project.--No work was done on this project.

GEOD 2-3.--We have extended the program for determining x, y, z correction from DOI residuals to handle an unlimited number of observations.

EPH 0.--We have rewritten this basic program and have completed the analysis to extend it to provide positional error estimates (based on the errors in the orbital elements). This analysis will be included in the program.

Simultaneous observations.--To make its output more meaningful, we have changed the format of the program to determine corrections to station coordinates in x, y, z from simultaneous observations.

New projects

SI SPOT.--This program was written to compute the position of a flashing satellite on a star chart to aid in the reduction of simultaneous observations.

In cooperation with Drs. Lautman and Colombo, we have written an integration program to investigate the effects of the earth's magnetic field on the motion of Explorer XI satellite.

We have written a program to compute and plot equipotential surfaces of the gravity anomaly deviation from a standard reference ellipsoid. Information input to this program is the output from the Tesseral Harmonic Program information. This project required a special program to compute associated Legendre polynomials. In addition, we computed a plotter deck to plot a map of the world showing the outlines of the continents.

We have initiated an integration program to investigate periodic and near-periodic orbits near the critical inclination.

System programming.--In preparation for installation of the IBM-7094 computer at Harvard, we are modifying the systems programs to make use of the extended operations available. In particular, we are altering the built-in floating-point double-precision hardware and the increased index registers. We also worked on improving the accuracy of some basic library mathematics routines.

Publications

During this reporting period the Computations Division has issued 15 program write-ups:

Gingerich, O., SIGIOH, Input Routine; Jan. 7, 1963

Gingerich, O., REREAD, Input Routine; Jan. 9, 1963

Young, A., BINOM, Binomial Coefficients Subroutine; Jan. 9, 1963

Gaposchkin, E. M., VCTRN, Vector Macro Package; Feb. 4, 1963

Young, A., HYPLOT, Graph Plotting with 1403 Printer; Feb. 4, 1963

Loeser, R., ENK, Using Console Switches in FORTRAN; Feb. 7, 1963

Taylor, R., CHKSUM, 1401 Program Checksum for Loading; Feb. 14, 1963

Gingerich, O., and Latham, D., MASTER, Control Program for Stellar Atmosphere Calculations; Feb. 21, 1963

Taylor, R., TUT, 1401 Tape-Unit/Tape Tester; Mar. 27, 1963

Gaposchkin, E. M., GIO, Input/Output Routine; Apr. 18, 1963

Joughin, W., SPLPLT, Point Plotting on EAI Dataplotter; Apr. 20, 1963

Feit, B., GEOD3, Geodetic Observation Residual Program; Apr. 30, 1963

Gingerich, O,, OPAC, Absorption Coefficient for H^- ion; May 13, 1963

Joughin, W., EPH 0, Ephemeris 0, new version; May 1963

Stein, M., SQRDBL, Double Precision Fixed Point Square Root; May 1963

DATA UTILIZATION

RESEARCH AND ANALYSIS

Satellite geodesy

Most of the work in this Division was devoted to satellite geodesy. By the beginning of the year there was a significantly large body of observational material at the investigators' disposal. The required computer programs had also developed to a satisfactory state. As a result, many machine-time-consuming least-squares solutions were carried out, both for the detection of tesseral harmonics and for the improvement of the coordinates of the 12 Baker-Nunn stations. Imre G. Izsak was responsible for the first of these projects; Mrs. Elizabeth Wombwell and Antanas Girnius, under the supervision of Dr. George Veis, for the second.

The tesseral-harmonics program presented difficulties, some of them unexpected. The residuals of the observations, especially those in the along-track direction, are by no means uniquely determined, because of the very nature of the differential orbit improvement that produced them. We usually get different residuals for the same observation if we fit to it two overlapping arcs of the orbit. For this and some other reasons special care is necessary in this very tedious phase of the work. Then, the distribution of a relatively small number of observations with respect to the arguments of the trigonometric functions that describe the perturbations is far from uniform. Worst of all, the effect of the different tesseral harmonics is not very much different in size and, for some terms, not even in shape. Therefore the perturbations caused by the various harmonics are hard to separate--a circumstance borne out by eventually considerable correlations among the unknowns. The only, but apparently rather efficacious, remedy for these difficulties seems to be the use of a large number of observations of satellites with a variety of orbital elements, particularly with different inclinations. After studying 9262 precisely reduced optical observations of five satellites, Mr. Izsak arrived at the following result, published in Nature:

$C_{22} = 9.68 \times 10^{-7}$	$C_{41} = 2.88 \times 10^{-7}$
$S_{22} = -4.00 \times 10^{-7}$	$S_{41} = -3.21 \times 10^{-7}$
$C_{31} = 1.12 \times 10^{-6}$	$C_{42} = 3.51 \times 10^{-8}$
$S_{31} = 6.16 \times 10^{-8}$	$S_{42} = 1.23 \times 10^{-7}$
$C_{32} = 9.12 \times 10^{-8}$	$C_{43} = 2.15 \times 10^{-8}$
$S_{32} = -1.83 \times 10^{-7}$	$S_{43} = 1.48 \times 10^{-8}$
$C_{33} = 7.17 \times 10^{-8}$	$C_{44} = 9.72 \times 10^{-9}$
$S_{33} = 1.24 \times 10^{-7}$	$S_{44} = 1.63 \times 10^{-8}$

Mrs. Gladys Johnson's computer program, which produced this output, underwent major changes during the past six months. It can now handle up to 44 unknowns, 38 of which may be tesseral-harmonics coefficients. Several simultaneous solutions for harmonics and station coordinates were also obtained. These results, however, need some further verification.

Another computer program, written by William Joughin, automatically plots the level curves of geoid heights and gravity anomalies on a world map.

Mrs. Elizabeth Wombwell prepared for Dr. Veis a huge body of material, consisting of about 30,000 photoreduced observations of seven satellites, for use in the GEO 3 program, which computes corrections to the station coordinates. Using this program she also obtained several preliminary solutions for the stations.

Mr. Girnius was responsible for handling simultaneous observations. By the end of this period about 40 such pairs of observations, secured at the Baker-Nunn stations in North and South America, were available. This and some additional material under preparation awaits final analysis by Dr. Veis.

Dr. Walter Köhnlein investigated trigonometry on a spheroid with different flattening at the north and south poles. He found a very accurate solution to the direct and indirect geodetic problem for geodesic lines of any length. He also developed special ellipsoidal transformations for the computation of datum shifts of large geodetic systems.

Chi-yuen Wang studied the correlation between undulations of the satellite-geoid and the distribution of the surface heat flow of the earth. He concluded that, in general, regions of hot and light material of the earth's mantle coincide with the areas of relatively low gravity. Such a phenomenon may well be explained by convection currents in the mantle resulting from temperature differences. Further data on heat flow and improved values of tesseral-harmonics coefficients are needed, however, to establish this correlation firmly.

Solar system

The study of the concentration of micrometeorites near the earth by Drs. Giuseppe Colombo and Don Lautman, in cooperation with Dr. Irwin Shapiro of the M.I.T. Lincoln laboratory, is continuing. Dr. Shapiro presented a paper at the April meeting of the AGU on the progress of this work up to that time. The team found that capture of interplanetary particles by atmospheric drag, with subsequent increase of lifetime from perturbations by solar-radiation pressure, can well explain the density of the particles. The lunar origin of micrometeorites seems unlikely unless more material is blasted off the moon by meteorite impact than is now thought possible.

The work of Drs. Colombo and Lautman on the elliptical restricted three-body problem is being extended to an orbital study of minor planets with periods nearly commensurate with that of Jupiter.

In another project of his own, Dr. Lautman found that the distribution of the minor planets' perihelia, as predicted by the theory of secular perturbation, substantially agrees with the observed distribution.

Atmospheric structure

Dr. Luigi G. Jacchia and Jack W. Slowey have continued their research on upper atmospheric structure and variations as determined from air drag on artificial satellites. Though the first instrumented satellite designed to study atmospheric structure (Explorer XVII) was launched in April, information of considerable interest is still coming from a careful analysis of the motions of suitable satellites in various orbits. A detailed study based on precisely reduced Baker-Nunn observations of the 12-foot balloon satellite, Explorer IX, was published in May. This study revealed that even the smallest geomagnetic disturbances are accompanied by a heating of the upper atmosphere. Previously, only fairly large disturbances had been detected in the motion of satellites. In the 283 days covered in the study, 46 atmospheric perturbations related to geomagnetic disturbances were resolved--an average of one every six days. The increase in the temperature of the atmosphere was found to vary linearly with the amplitude of the geomagnetic disturbance, Δa_p.

Soon to be published are results of a study based primarily on Minitrack and field-reduced Baker-Nunn observations of the auroral satellite, Injun III, launched last December. This study has revealed that the atmospheric heating that accompanies geomagnetic disturbances is about five times greater in the auroral zones than it is at low latitudes. This could have been expected but had not been observed previously for lack of a suitable satellite with high orbital inclination. In addition, the analysis demonstrates that there is little if any latitude effect, i.e., the added heating occurs only on magnetically disturbed days and not on quiet days. Mr. Slowey will present a preliminary paper on this material to the American Astronomical Society in July.

Flare-star observations

Leonard H. Solomon is continuing a program of optical observations of flare stars. Stellar flares have amplitudes of from several hundredths of a magnitude to several magnitudes over a time scale of minutes. No periodicity is observed. Energy considerations indicate that these flares resemble those of the sun. If this is so, they may produce sufficient energy in the radio spectrum to be observed from the earth.

Since 1960 six Baker-Nunn cameras have photographed flare stars in conjunction with radio-frequency measurements of their radio emissions. The cooperating radio observatories are Jodrell Bank Experimental Station, University of Manchester, England, and the Commonwealth Scientific and Industrial Research Organization at Sydney, Australia.

The photographic procedure consists of exposing a frame for several seconds, at intervals of two minutes. The exposure times are only long enough to record the star at minimum light, as the changes in brightness are sufficiently fast to affect the observed light curve if long time exposures are used. We can cover long time periods with minimum effort and effect on other observations by photographing at serial times from several stations widely separated in longitude, centered on the radio observatory longitude. In this way we cover up to six hours in any night's observing. The Baker-Nunn network is well suited for this work because of the distribution of stations and the extreme speed of the cameras.

The photographic coverage in fiscal 1963 amounted to 410 hours, of which 350 were combined with radio measurements. Only one large flare has been found in this year's observations, but most of the data has not yet been reduced. Reduction of previous years' films produced some 23 minor bursts, that correlate with increases in radio energy observed at Jodrell Bank. The chance that the correlation is spurious is one in 10^8. The one major flare observed this year correlates in time with a major burst observed in the radio spectrum at Sydney. These combined observations appear significantly correlated; if they are, they constitute the first observations of radio energy from "normal" stellar objects. We expect that further, more refined observations will lead to a theory for the stellar production of flares.

EDITORIAL AND PUBLICATIONS

The Satellite Tracking Program issued the following Special Reports during this six-month period:

No. 112 -- On the Secular Decrease in the Inclination of Artificial Satellites, by R. C. Nigam.

No. 113 -- Satellite Orbital Data, material prepared under the supervision of I. G. Izsak.

No. 114 -- Catalogue of Satellite Observations (C-31), prepared by B. Miller.

No. 115 -- Catalogue of Satellite Observations (C-32), prepared by B. Miller.

No. 116 -- Catalogue of Satellite Observations (C-33), prepared by B. Miller.

No. 117 -- Satellite Orbital Data, material prepared under the supervision of I. G. Izsak.

No. 118 -- Catalogue of Precisely Reduced Observations (P-8), compiled by Phyllis Stern, Data Division.

No. 119 -- Satellite Orbital Data, material prepared under the supervision of I. G. Izsak.

No. 120 -- Satellite Orbital Data, material prepared under the supervision of I. G. Izsak.

No. 121 -- Smithsonian Astrophysical Observatory Program Writeup (SCROGE), by J. R. Cherniack and E. M. Gaposchkin.

No. 122 -- Combinations of Least-squares Approximations in the Case of Correlated Variables, by P. L. Kadakia.

No. 123 -- Precise Aspects of Terrestrial and Celestial Reference Frames, by G. Veis.

No. 124 -- Notes on the Design and Operation of Satellite Tracking Stations for Geodetic Purposes, by the Staff of the Smithsonian Institution Astrophysical Observatory.

No. 125 -- An Analysis of the Atmospheric Drag of the Explorer IX Satellite from Precisely Reduced Photographic Observations, by L. G. Jacchia and J. Slowey.

No. 126 -- Satellite Orbital Data, material prepared under the supervision of B. Miller.

The following papers by staff members appeared in various journals during Fiscal Year 1963. Also published in 1963 were several articles indirectly concerned with the satellite program.

Briggs, R. E. Steady-state space distribution of meteoric particles under the operation of the Poynting-Robertson effect. Astron. Journ., vol. 67, p. 710, 1962.

Colombo, G. The magnetic torque acting on artificial satellites. Proceedings of Conference on Gyrodynamics, I.U.T.A.M., Celerina, 1963.

__________. See also Shapiro, Lautman, and Colombo.

Colombo, G., and Lautman, D. A. On some singular orbits of an Earth-Moon satellite with a high-area mass ratio (abstract). Astron. Journ., vol. 67, p. 573, 1962.

Colombo, G.; Lautman, D. A.; and Munford, C. On the libration orbits of a particle near the triangular points on the semirestricted three-body problem (abstract). Astron. Journ., vol. 68, pp. 159-162, 1963.

Izsak, I. G. The odd harmonic effect in the motion of the satellites 1960 Beta 2 and 1960 Iota 2. Proceedings of the First International Symposium on the Use of Artificial Satellites for Geodesy, p. 329, North-Holland Publishing Co., Amsterdam, 1963.

__________. On the critical inclination in satellite theory. Proceedings of the First International Symposium on the Use of Artificial Satellites for Geodesy, p. 117, North-Holland Publishing Co., Amsterdam, 1963.

Jacchia, L. G. Comment on paper by D. G. Parkyn, Satellite 1958 δ2 Data Analysis. Journ. Geophys. Res., vol. 67, p. 2989, 1962.

__________. The determination of atmospheric drag on artificial satellites. Dynamics of Satellites, I.U.T.A.M. Symposium, Paris, pp. 136-142, Springer-Verlag, Berlin, 1963.

Jacchia, L. G. Electromagnetic and corpuscular heating of the upper atmosphere. Space Research III, North-Holland Publishing Co., Amsterdam, 1963.

____________. Meteors, meteorites and comets; interrelations. In G. Kuiper and B. Middlehurst, ed., The Solar System, vol. IV, pp. 774, University of Chicago Press, 1963.

____________. Satellite studies of the upper atmosphere. Trans. Amer. Geophys. Union, vol. 44, p. 436, 1963.

Kozai, Y. Mean values of cosine function in an elliptic motion. Astron. Journ., vol. 67, p. 311, 1962.

________. Second-order solution of artificial satellite theory without air-drag. Astron. Journ., vol. 67, p. 446, 1962.

________. Secular perturbations of asteroids with high inclination and eccentricity. Astron. Journ., vol. 67, pp. 591-598, 1962.

________. Numerical results on the gravitational potential of the earth. Proceedings of the First International Symposium on the Use of Artificial Satellites for Geodesy, p. 305, North-Holland Publishing Co., Amsterdam, 1963.

________. Potential of the earth derived from satellites motion. In M. Roy, ed., Dynamics of Satellites, Springer-Verlag, Berlin, 1963.

Lautman, D. A. On the distribution of the perihelia of the asteroids (abstract). AAS, 1963.

____________. See also Shapiro, Lautman, and Colombo; Colombo and Lautman; Colombo, Lautman, and Munford.

Lovell, B.; Whipple, F. L.; and Solomon, L. Radio emission from flare stars. Nature, vol. 198, pp. 228-230, 1963.

Lundquist, C. A.; Naumann, R. J.; and Weber, A. H. Directional flux densities and mirror point distributions of trapped particles from satellite 1958 Epsilon measurements. Journ. Geophys. Res., vol. 67, p. 4125, 1962.

Munford, C. See Colombo, Lautman, and Munford.

Nigam, R. C. Secular decrease in the inclination of artificial satellites. AIAA Journ., p. 1455, June, 1963.

Shapiro, I. I.; Lautman, D. A.; and Colombo, G. Capture of cosmic dust into circumterrestrial orbits. Trans. Amer. Geophys. Union, vol. 44, p. 71, 1963.

Solomon, L. See Lovell, Whipple, and Solomon.

Whipple, F. L. Dust and meteorites. Astronautics, vol. 7, pp. 40-42, 1962.

___________. Meteoritic erosion in space (abstract). Astron. Journ., vol. 67, pp. 285-286, 1962.

___________. Meteoritic erosion in space. Smithsonian Contr. Astrophys., vol. 7, pp. 239-248, 1963.

___________. On the structure of the cometary nucleus. In G. Kuiper and B. Middlehurst, ed., The Solar System, vol. IV, chap. 15, pp. 639-662, University of Chicago Press, 1963.

___________. See also Lovell, Whipple, and Solomon.